FILE COPY

Lab. Records
Keep with Notice

Contract W-7405 eng-39

[redacted]

CH - 2565
G - A

Copy 5A
#340

OPERATING EQUATIONS AND PROCEDURES
INVOLVED IN WATER COUNTING AT SITE "X"

by K. Z. Morgan
January 1945

DECLASSIFIED Per Letter Instructions Of
AEC 10-26-53
With/D
1/13/54 W C Brown for W. T. Bray
SUPERVISOR CENTRAL FILES
ORNL

Received Clinton: 1/13/45 Series A Issued: 1/15/45
Received Chicago: Series B Issued:

[redacted]
person is prohibited [redacted]

[redacted]

[redacted] [redacted]

Table of Contents

[redacted]

OPERATING EQUATIONS AND PROCEDURES INVOLVED IN WATER COUNTING AT SITE "X"

Ref: CH-1889; Project Handbook, Chapter XII, TNX 7, and CH-1619.

Readings to determine the radioactivity of the waste in the disposal water from Clinton Laboratories are made both by Health-Physics Section and the Analytical Section. The Health-Physics measurements are made each day and are used to determine the gamma-activity of the settling pond and of White Oak Lake. The Analytical Section measures the beta counts/minute of an evaporated 5 cc sample from the settling pond once each shift. Once a month, an analysis is made on an accumulated sample of water from White Oak Lake (composed of the sum of small samples that were collected each day of the month) to determine the radioactive elements present. This element analysis is used in determining the average beta and gamma energies of the radioactive materials in the water. At present it is considered that tolerance is set by the external radiation to a submerged body. This is the case as long as the principle activity in the water is due to Cb and Zr, and the percents of Ba and Sr (which are readily deposited in the bone) remain rather low. Experiments with goldfish seem to indicate that when Sr is adsorbed on clay it is not absorbed into the body. If this is true for humans as well as for fish, and for other elements, the ingestion tolerance limits are of less concern than the external radiation tolerance limits.

A. Gamma Readings

1. Two Vessel Method. Measurements are made of the activity of the water from the settling pond and from White Oak Lake by the following method. A standard thin-walled glass counter** with an effective cross-sectional area for gamma radiation of 5.4 cm^2 is enclosed in a brass cylinder with walls of sufficient thickness to absorb all the beta radiation. This counter is placed along the axis at the center of a cylindrical vessel, 14" in diameter, which is filled with water to a depth of 12". The counting rate is determined with the aid of a "scale of 64" circuit. Readings are made first with freshly drawn drinking water in the vessel to determine the background, and then with the sample water. The procedure is repeated using a vessel of half the diameter of the former one, i.e. 7".

**NOTE: Originally a small brass counter was used for this purpose but had to be replaced with the glass counter since the Clinton Laboratories shop was unable to supply the brass counters. The glass counters have not proved very satisfactory. In order to use them a large brass cylinder had to be constructed to contain them, due to the glass electrode nipple on the side of the counter. Ideally one would like the counter and its container to be as small as possible. We will return to using a brass counter and its smaller container as soon as a satisfactory brass counter can be provided.

[redacted]

[redacted]

The reason for using two vessels, one twice the diameter of the other, is to obtain a correctin factor for the absorption in water and to determine the activity that would be received by a body submerged in a large volume of this water, without having to assume anyenergy distribution. This fact is shown by an inspection of Equation 1 below, in which the ionization intensity, I, of the gamma radiation from the radioactive material in the water is expressed independently of the coefficient of absorption. In using this equation, however, one should remember that the conversion factor, 1/C, is a function of the energy and a slight error is introduced when one sets it equal to 3350 counts/minute/mr/hr for low energies of gamma-radiation.

The Equations used in this procedure were given by H. M. Parker in CH-1889 and are developed as follows.

Let D equal the dosage rate at 1 cm from a unit volume of active material. If the unit volume of a shell about a sphere is $4\pi r^2\,dr$, the dosage rate at the center of a sphere of this material of radius R will be:

$$\int_0^R \frac{4\pi r^2 D e^{-\mu R}\,dr}{r^2} = \frac{4\pi D}{\mu}(1 - e^{-\mu R})$$

When $R \longrightarrow \infty$, $\frac{4\pi D}{\mu}(1-e^{-\mu R}) \longrightarrow \frac{4\pi D}{\mu}$. Therefore, $\frac{4\pi D}{\mu}$ is the dosage rate at a point surrounded by an infinite volume of radioactive material. If we set $\frac{4\pi D}{\mu} = K_\infty$, $R \equiv$ radius of the large vessel and $R/2 \equiv$ of the small vessel we have:

$$L = K_\infty(1-e^{-\mu R}) \text{ and}$$

$$S = K_\infty(1-e^{-\mu R/2})$$

in which,

L = c/m with the large vessel of radius R

S = c/m with the small vessel of radius R/2

A simultaneous solution of the two equations above gives:

$$I = CK_\infty = \frac{CS^2}{2S-L} = \frac{S^2}{(2S-L)\,3350} = \frac{3 \times 10^{-4}\,S^2}{2S-L} \text{ mr/hr} \qquad (1)$$

[redacted]

[redacted]

in which:

$1/C$ = Conversion factor from c/m to mr/hr (1 mr/hr $\doteq$ 3350 c/m)
I = Ionization intensity due to gamma rays in water in mr/hr.

Thus the readings L and S which are corrected for background are substituted in equation (1) to determine the mr/hr due to gamma radiation in the water.

2. Single Vessel Method. A simplified procedure for obtaining the ionization intensity in the water (= I) is to make use of the average gamma-ray energy of the radioactive materials in the water as determined from the monthly analysis of the water. The Zr and Cb seem to comprise at present a large percent of the activity of the water when it is freed from the suspended clay. Therefore, the average gamma-ray energy is probably about 0.7 mev. The value of the coefficient of absorption corresponding to 0.7 mev is .074 cm^{-1} of water (see fig. 4 in TNX-7). Substituting this value in the above equations, one obtains:

$$S = K_\infty\left\{1 - e^{-.074(\frac{7}{2}x2.54)}\right\} = K_\infty\left\{1 - .52\right\} = K_\infty(.48)$$

$$I = CK_\infty = 6.2 \times 10^{-4}\ S \quad mr/hr \qquad (2)$$

Likewise

$$I = 4.1 \times 10^{-4}\ L \quad mr/hr \qquad (3)$$

If the average γ-ray energy should increase to 1.0 mev, the value of μ would be 0.064 cm^{-1} of water. This would give values of I as follows:

$$I = 6.9 \times 10^{-4}\ S \quad mr/hr \qquad (2)'$$

$$I = 4.4 \times 10^{-4}\ L \quad mr/hr \qquad (3)'$$

It is obvious, therefore, that the above relation is not very critical with energy and that rather satisfactory results can be obtained directly from equation (2) or (3) so long as the conversion factor (1/C = 3350 c/m/mr) does not change very much over the range of energies used.

[redacted]

[redacted]

3. Direct Method. (Portable Submersible Counter) The simplest method for finding the water activity is to submerge the portable submarine counter from the boat directly into White Oak Lake and obtain the rate N' in c/m.

This submarine counter is enclosed in a steel pipe and is submerged to the proper depth from a standard life preserver. The counter is one of the standard glass wall type and feeds directly into a portable "scale of two" circuit. This apparatus is moved to the desired location in the Lake and in the Clinch River below the lakes. The outstanding advantage of thisapparatus is that it is used to make measurements directly and requires only a few minutes for each reading.

The intensity in mr/hr is given by the following equation:

$$I = \frac{N'}{3350} = 3 \times 10^{-4} N \quad mr/hr \tag{4}$$

In using this method the submarine counter is first submerged in a large tank containing plant drinking water, in order to obtain the background correction for N.'

The submarine counter method cannot be used in the settling pond because of the high background radiation from the bottom and top of the settling pond. Good results can be obtained in White Oak Lake or in the Clinch River if the submarine counter is submerged to about one foot below the surface and five feet (or more) above the bottom of the lake.

If one wishes to determine the activity of the material in the water in terms of μ c/liter of water from the values of I in mr/hr, this can be done most eaily by assuming the energy absorbed in the water is equal to the energy emitted. Thus one sets up the equation:

$$I = \frac{\text{ion pairs}/\ 1}{cc/1} \quad 4.8 \times 10^{-10} \times sec/hr \times mr/r \times \text{density air}$$

$$I = \frac{3.7 \times 10^{4}\ M\ E \times 10^{6} \times 4.8 \times 10^{-10} \times 3600 \times 10^{3} \times 0.00129}{32 \times 10^{3}}$$

In which M = concentration of gamma emitting radioactive materials in μ c/liter of water

E = energy of activity in mev

I = ionization intensity in mr/hr as determined by ~~eqs~~ 1, 2, 3, or 4
eqs.

[redacted]

This equation reduces to:

$$M = \frac{0.388\ I}{E}\ \mu c/\text{liter of water} \qquad (5)$$

As a close approximation to average conditions, E may be taken as 0.7 mev for gamma-radiation in the water and then equation (5) becomes:

$$M = .55\ I\ \mu c/\text{liter of water} \qquad (5)'$$

If one sets I = 4.17 mr/hr (the accepted tolerance rate for 24 hours) in equation (5) it becomes:

$$M = \frac{1.6}{E}\ \mu c/\text{liter of water} \qquad (6)$$

which is the conventional equation for determining submersion tolerance concentration of water. The equations (5), (5)', and (6) are true for both gamma and beta radiation.

According to equation (5)' the submersion tolerance concentration of the water in White Oak Lake (if E = 0.7 mev) is M = 0.55 I = 2.3 μc/liter of water. This agrees with the value given by H. M. Parker in CH-1889.

B. <u>Beta Readings</u>

This data is furnished each shift to our Section by the Analytical Section in terms of count/min/ml of water from both the effluent and affluent water of the settling pond. This can be converted to water activity concentration as follows:

$$M_\beta = \frac{n \times 10^3}{3.7 \times 10^4 \times 60} = 4.5 \times 10^{-4}\ n \qquad (7)$$

In which M_β = beta activity concentration in μc/liter of water
n = total corrected beta counting rate in c/m/ml

In order to obtain n, one must correct for the geometry factor (~ 10) back scattering factor ($\sim \frac{1}{1.3}$) and absorption factor ($\sim e^{6 \times .01}$ = 1.06. (See report by H. M. Parker, CH-1889).
Therefore -

$$n = 10 \times \frac{1}{1.3} \times 1.06\ N = 8\ N \qquad (8)$$

and equation (7) becomes:

$$M_\beta = 4.5 \times 10^{-4} \times 8N = 3.6 \times 10^{-3}\ N \qquad (9)$$

in which N = uncorrected experimental value of c/m/ml as submitted to Health-Physics Section by the Analytical Section.

[redacted]

In order to check the experimental procedure, a tolerance solution of UNH was used (CH-1889). If the average energy of the beta-rays in this uranium test solution was 0.9 mev, one would expect the tolerance value to be:

$$M_{\beta} = \frac{1.6}{E} = 1.8\ \mu c/\text{liter of water} \tag{10}$$

Actually the average energy of the activity of the discharge water from Clinton Laboratories is probably not far from 0.3 mev and not .9 mev. In this case the tolerance concentration is:

$$M_{\beta} = \frac{1.6}{E} = 5\ \mu c/\text{liter of water} \tag{11}$$

and the tolerance counting rate would become:

$$N = \frac{M_{\beta}}{3.6 \times 10^{-3}} = \frac{5}{3.6 \times 10^{-3}} = 1400\ c/m/ml \tag{12}$$

In practice submersion tolerance for beta radiation is usually twice the values indicated in (10), (11), and (12) since for large bodies submerged in the water the radiation enters only from 2π degrees. However, the above equations are used in practice here in order to add a factor of safety and to cover the few instances (such as fish eggs or a man's ears) in which beta radiation can enter from all directions.

The mr/hr for beta-radiation can be found from equation (5), i.e. placing the value of M as found above in equation (5):

$$I_{\beta} = \frac{M_{\beta}\ E}{0.388}\ \text{mr/hr*} \tag{13}$$

A portable submarine thin-walled beta-counter is being experimented with at present. If it proves satisfactory for general use, the equation used will be similar to equation (4) or -

$$I_{\beta} = \frac{N}{K}$$

in which N = c/m corrected for background and
K = conversion factor for beta-radiation from activity in water.

C. Appendix

Example: Given a water sample from the settling pond effluent with a beta activity of N = 250 c/m and with gamma-activity measurements of S = 2000 c/m and L = 2900 c/m. The reading with the submarine counter in White Oak Lake was N = 90 c/m. All readings are corrected for background.

* NOTE: Mr is used here to mean mrep (1/1000 of a roentgen equivalent physical).

[redacted]

[redacted]

Gamma Activity in Settling Pond Effluent

Eq. (1): $I_\gamma = \dfrac{3 \times 10^{-4}\, S^2}{2\, S-L} = \dfrac{3 \times 10^{-4}\, (2000)^2}{1100} = 1.1$ mr/hr

Eq. (2): $I_\gamma = 6.2 \times 10^{-4}\, S = 6.2 \times 10^{-4}\, (2000) = 1.2$ mr/hr

Eq. (3): $I_\gamma = 4.1 \times 10^{-4}\, L = 4.1 \times 10^{-4} \times 2900 = 1.2$ mr/hr

Eq. (5)': $M_\gamma = 0.55\, I_\gamma = 0.55\, (1.2) = .66\, \mu c$/liter of water

Beta Activity in Settling Pond Effluent

Eq. (9): $M_\beta = 3.6 \times 10^{-3}\, N = .9\, \mu c$/liter of water

Eq. (13): $I_\beta = \dfrac{M_\beta\, E}{0.388} = \dfrac{0.9(.3)}{.388} = .7$ mr/hr

Total Activity in Settling Pond Effluent

$I_{\beta+\gamma} = .7 \times 1.2 = 1.9$ mr/hr

$M_{\beta+\gamma} = .9 + .66 = 1.56\, \mu c$/liter of water

} 45% of tolerance for submersion

If the effluent of the settling pond is 800,000 gal/day ($800,000 \times 3.785 = 3 \times 10^6$ liter/day), the total activity discharge per day at the above rate is $3 \times 10^6 \times 1.56 \times 10^{-6} = 4.7$ curie/day

Gamma Activity of White Oak Lake

Eq. (4): $I_\gamma = \dfrac{N}{3350} = \dfrac{90}{3350} = .027$ mr/hr

Eq. (5)': $M_\gamma = 0.55\, I_\gamma = 0.55(.027) = 0.015\, \mu c$/liter of water.

[redacted]